5.0 AQUIFER RECHARGE

This section develops and presents information that has been incorporated into the conceptual model describing risks associated with the aquifer recharge wastewater management option.

5.1 Definition of Aquifer Recharge

Aquifer recharge in its broadest sense refers to the replenishment or recharge of a groundwater aquifer. In Florida, a number of practices involving use of reclaimed water may be termed aquifer recharge. *Reclaimed water* is wastewater that has received at least secondary treatment and basic disinfection or better and that is reused after leaving a municipal wastewater treatment facility. *Reuse* means the application of reclaimed water for a beneficial purpose (FDEP, 2001b). Reuse of reclaimed water is strongly supported and instituted in state law to encourage water conservation (FDEP, 2001c). Beneficial uses include irrigation, recharge of groundwater through rapid- or slow-rate land application, and enhancement or creation of wetland habitat. Reuse does not include direct consumption of water by humans.

The types of reuse allowed in Florida (FDEP, 1998) that involve aquifer recharge are listed below:

- Slow-rate land application systems (restricted public access)
- Rapid-rate land application systems
- Irrigation of public-access areas
- Rapid infiltration basins (RIBs)
- Unlined storage ponds
- Discharge to wetlands that percolate to groundwater
- Septic tanks
- Injection to groundwater
- Aquifer storage and retrieval
- Injection for salinity barriers
- Deep injection wells.

The first seven uses of reclaimed water involve application of treated water on or near the surface of the land, allowing percolation of the water to occur through soil. The last four uses of reclaimed water involve active injection of treated wastewater or other water into the ground at various depths. An example of the latter is aquifer storage and retrieval (ASR). ASR typically involves the storage of excess drinking-water-quality water in a subsurface aquifer for later recovery and use during periods when demand for drinking water exceeds availability. Although reclaimed water may be used, ASR typically is not used to dispose of treated wastewater but is instead aimed at temporarily storing drinking water. Reuse that involves discharges of reclaimed water to surface water is described in Chapter 7.

For this risk assessment, several types of reclaimed water reuse that may result in aquifer recharge were evaluated. These include slow-rate land application systems (including irrigation), rapid-rate land application systems (including RIBs and unlined storage ponds), and wetland treatment systems. These types of aquifer recharge are characterized by surface application of reclaimed water over an area and allowing the water to percolate downward and outward from the point of application.

Other practices involving reuse of reclaimed water or use of drinking-water-quality water were not evaluated in this risk assessment. These include Class V shallow-injection wells for disposal of treated wastewater, ASR systems, salinity barriers, and septic systems. Class V shallow-injection wells, which are regulated by federal and state regulations, are used for disposal of industrial, as well as treated, municipal wastewater and were not evaluated in this risk assessment. ASR was not evaluated because it often utilizes surface water rather than reclaimed water, as described above. Salinity barriers were not evaluated because they are not intended for disposal of wastewater. This risk assessment does not address on-site sewage disposal systems such as septic systems, a wastewater management option that serves about 25% of Florida's population. Nevertheless, where reclaimed water is used for such purposes, the risk analysis presented here may be applicable.

5.2 Use of Aquifer Recharge in South Florida

The Division of Water Resources Management of the Florida Department of Environmental Protection (DEP) conducts yearly inventories of all active domestic wastewater treatment facilities that provide reclaimed water for reuse. The DEP's *2000 Reuse Inventory* lists facilities having permitted capacities of at least 0.1 million gallons per day (mgd) or more and describes reuse activities throughout the state of Florida (FDEP, 2001a).

Types of reuse included in the DEP inventory are irrigation of public-access areas, landscape irrigation, agricultural irrigation, groundwater recharge, indirect potable reuse, industrial uses, wetlands, and other uses. Irrigation of public-access areas and landscapes includes irrigation of golf courses, residential areas, and other public-access areas. Agricultural irrigation includes irrigation of edible and inedible crops. Groundwater recharge and indirect potable reuse includes RIBs, absorption fields, surface-water augmentation, and injection. Industrial uses include those at the treatment plant or at other facilities. Wetland uses include discharge to wetlands and creation or enhancement of existing wetlands.

According to the *2000 Reuse Inventory* (FDEP, 2001a), the leading use of reclaimed water in Florida is irrigation of public-access areas and landscapes (Tables 5-1 and 5-2), totaling 107,123 acres, by far the largest area covered by any reuse activity. Agricultural irrigation accounts for the second-largest area receiving reclaimed water (35,282 acres). Groundwater recharge in Florida accounts for 7,418 acres, while wetland uses of reclaimed water account for 4,791 acres. Altogether, 154,954 acres receive reclaimed water through various types of reuse activities.

Table 5-1. Reclaimed Water Reuse Activities in Florida

Reuse Type	No. of Systems[1]	Capacity (mgd)	Flow (mgd)	Area (acres)
Public-access areas and landscape irrigation				
Golf course irrigation	179	241	108	46,730
Residential irrigation	82	163	95	39,896
Other public-access areas	98	99	44	20,497
Subtotal:[2]	359	503	247	107,123
Agricultural Irrigation				
Edible crops	21	54	35	14,414
Other crops	96	133	73	20,868
Subtotal:[2]	117	187	108	35,282
Groundwater recharge and indirect potable reuse				
Rapid infiltration basins	169	171	85	6,969
Absorption fields	20	8	3	449
Surface-water augmentation	0	0	0	NA
Injection	1	10	8	NA
Subtotal:[2]	190	189	96	7,418
Industrial				
At treatment plant	76	129	66	4
At other facilities	17	35	21	0
Subtotal:[2]	93	164	87	4
Toilet flushing	3	0	0	NA
Fire protection	0	0	0	NA
Wetlands	14	66	32	4,791
Other uses	10	7	5	336
Totals:[2]	**427**	**1,116**	**575**	**154,954**

[1]The numbers of facilities are not additive because a single facility may engage in one or more reuse activity.
[2] Discrepancies in column totals are from internal rounding associated with the development of this summary table.
Source: FDEP, 2001a.

Table 5-2. Reuse Flows for Reuse Types in Florida DEP Districts and Water Management Districts

Districts	Irrigation of Public-access Areas (mgd)	Agricultural Irrigation (mgd)	Ground-water Recharge (mgd)	Industrial (mgd)	Wetland Systems and Others (mgd)	Totals (mgd)
DEP Districts						
Southeast (West Palm Beach)	25.98	0.94	7.68	27.12	1.52	63.24
South (Fort Myers)	52.37	5.06	8.60	1.18	2.28	69.49
Southwest (Tampa)	79.89	21.50	15.44	30.80	6.64	154.27
Subtotal, DEP districts in South Florida study area	**158.24**	**27.5**	**31.72**	**59.1**	**10.44**	**287.00**
Central (Orlando)	71.69	43.90	50.17	15.96	21.84	203.56
Northeast (Jacksonville)	9.45	6.63	10.73	5.35	0.63	32.79
Northwest (Pensacola)	8.62	30.09	3.50	5.92	3.85	51.98
Totals, all DEP districts	**248.00**	**108.12**	**96.12**	**86.33**	**36.76**	**575.33**
Water Management Districts						
South Florida[1]	90.34	23.14	43.47	28.81	3.81	189.57
St. John's River[2]	67.16	25.05	31.11	20.64	22.37	166.33
Southwest Florida[2]	81.77	23.56	17.12	30.89	6.71	160.05
Northwest Florida	8.62	30.18	3.50	5.92	3.88	52.10
Suwannee River	0.11	6.19	0.93	0.06	0.00	7.29
Totals , all water management districts:	248.00	108.12	96.13	86.32	36.77	575.34

[1]The area covered by the South Florida Water Management District is smaller than the area of this study.
[2]Approximately half of these water management districts are outside of the area of this study.
Source: FDEP, 2001a.

As Table 5-2 indicates, use of reclaimed water for public-access areas accounts for the largest flows of reclaimed water in Florida (248 mgd), followed by agricultural irrigation (108.12 mgd), groundwater recharge (96.12 mgd), industrial use (86.33 mgd), and wetlands (36.76 mgd), based on DEP districts. In the South Florida study area, use of reclaimed water for public access is also the leading use (158.24 mgd), followed by industrial use (59.1 mgd), groundwater recharge (31.72 mgd), irrigation (27.5 mgd), and wetlands (10.44 mgd), based on DEP districts.

The DEP *2001 Reuse Inventory* states that Florida has 359 systems using reclaimed water for irrigation of public-access areas and landscape irrigation, of which approximately one-half (179) are golf-course irrigation systems. The other systems are nearly evenly divided among those serving other public-access areas (98) and residential irrigation (82).

According to the Florida DEP, reuse of reclaimed water on golf courses accounts for 42 percent of all reuse in Florida (FDEP, 2002). Agricultural irrigation systems using reclaimed water total 117. These two types of irrigation involve slow-rate land application. Industrial systems total 93. In the category of ground water recharge, there are 189 reuse systems utilizing rapid-rate land application (169 RIBs plus 20 absorption fields), out of a total of 427 reuse systems in the state. There are 14 wetlands systems using reclaimed water (see Table 5-1).

It is important to note that, to provide flexibility in meeting discharge requirements, a wastewater treatment facility may utilize more than one wastewater management option. Similarly, more than one type of reuse system may be used at a particular site (FDEP, 2001a).

5.3 Environment into Which Treated Wastewater is Discharged

Aquifer recharge involves surface infiltration and percolation of treated reclaimed wastewater through soils and geologic media overlying the surficial aquifer or the Biscayne Aquifer, depending on the location. In Dade County, the Biscayne Aquifer receives recharge. In Pinellas and Brevard counties, the unnamed surficial aquifer receives recharge. The Biscayne and surficial aquifers are described below. See chapters 2 and 4 for more detailed information on these aquifers.

5.3.1 Biscayne Aquifer System

The Biscayne Aquifer covers an area of approximately 4,000 square miles of South Florida (USGS, 2000). This aquifer extends along the eastern coast from southern Dade County into coastal Palm Beach County. It is located above the Floridan Aquifer, separated by approximately 1,000 feet of low-permeability clay deposits. The Biscayne Aquifer ranges in thickness from 50 to 830 feet and is composed of highly permeable limestone or calcareous sandstone (Meyer, 1989; Reese, 1994; Maliva and Walker, 1998; Reese and Memburg, 1999; Reese and Cunningham, 2000).

The Biscayne Aquifer system is the main source of water for Dade, Broward, and southeastern Palm Beach counties and serves the cities of Boca Raton, Pompano Beach, Fort Lauderdale, Hollywood, Hialeah, Miami, Miami Beach, and Homestead. According to the U.S. Geological Survey, this aquifer is the sole source of drinking water for 3 million people. Because the Biscayne Aquifer lies close to the surface and is highly permeable, it is highly susceptible to contamination.

5.3.2 Surficial Aquifer

In areas of South Florida outside the Biscayne Aquifer, the unnamed surficial aquifer is used locally for community and public water supply. The surficial aquifer is composed of relatively thin layers of sands and limestone. The surficial aquifer ranges in thickness from 20 to 800 feet, reaching its greatest thickness in southeastern Florida (Adams, 1992; Barr, 1996; Lukasiewiez and Adams, 1996; Reese and Cunningham, 2000). Although the surficial aquifer yields relatively small volumes of water, it is an important source of private water supplies (Miller, 1997).

5.4 Regulations and Requirements for Aquifer Recharge

The level of wastewater treatment required for various reuse options is specified in state regulations, including chapters 62-600 of the Florida Administration Code (FAC) (Domestic Wastewater Facilities), 62-610 FAC (Reuse of Reclaimed Water and Land Applications), and 62-611 FAC (Wetland Applications).

In addition to required treatment levels, state regulations specify system design and operational requirements regarding facility capacity, monitoring requirements, backup systems, and setback distances. All potable and nonpotable water supply wells and monitoring wells within a 0.5-mile radius of reclaimed-water facilities must be identified in permit applications for reclaimed-water facilities. Engineering reports must demonstrate that reclaimed water or effluents will not violate water quality standards.

Reclaimed-water systems may be located in areas that have Class F-I, G-I, and G-II groundwaters for potable-water use, as defined by Rule 62-520 FAC (DEP 1996 Ground Water Standards and Exemptions). Reclaimed-water facilities are required by EPA Class I reliability regulations to provide backup treatment and wastewater-holding capability in the event that treatment is disrupted or interrupted. Redundant treatment, recirculation and retreatment, and the use of holding ponds with extra capacity are examples of backup treatment and retention methods.

Sampling for *Cryptosporidium* and *Giardia* is required for discharges that may potentially affect Class I surface waters and is also required for groundwater recharge or salinity-barrier-control discharges. Although there are no federal or state numerical standards for pathogenic protozoans in reclaimed water, the Florida DEP recommends that concentrations of *Cryptosporidium* and *Giardia* should not exceed 5.8 oocysts and 1.4 oocyst per 100 liters (L), respectively (York et al., 2002).

5.4.1 Slow-Rate Land Application Systems

Slow-rate land application involves the discharge of treated water to the land's surface and the eventual percolation of this water through soils and rocks, leading to aquifer recharge. To prevent surface runoff or ponding of the applied reclaimed water, hydraulic loading rates are regulated. The loading rate is established after considering the ability of the plant and soil system to remove pollutants from the reclaimed water and the infiltration capacity and hydraulic conductivity of geologic materials underlying the system. Slow-rate land application systems typically are designed with hydraulic loading rates between 0.15 and 1.6 centimeters per day (cm/day) (US EPA, 1981; Metcalf and Eddy, 1991; Water Environment Federation, 1992; Kadlec and Knight, 1996).

Slow-rate land application systems must have backup disposal methods for wet weather conditions and when water quality treatment standards are not met. During wet weather, effluent may be discharged to storage areas or discharged through an alternative permitted disposal system.

In restricted access areas, reclaimed water must be provided with secondary treatment and basic disinfection. In public-access areas, reclaimed water must receive secondary treatment with high-level disinfection, at a minimum. Concentrations of total suspended solids must be reduced through methods such as filtration or addition of substances that cause coagulation, such as polyelectrolytes. Filtration increases the effectiveness of disinfection, particularly for removing cyst-forming pathogenic protozoans such as *Cryptosporidium parvum* and *Giardia lamblia*. Because of the potential for public exposure to many reuse projects, particular care is necessary to minimize the spread of pathogens (FAC 62-610, Part III, Slow-Rate Land Application Systems: Public Access Areas, Residential Irrigation, and Edible Crops).

All land application systems, whether slow-rate or rapid-rate, must maintain setback distances to surface water and potable supply wells to protect water quality and ensure compliance with water quality and drinking-water standards. For example, RIBs, percolation ponds, basins, trench embankments, and absorptions fields must be set 500 feet from potable-water wells or Class I or II waters. The setback distance to potable-water wells can be reduced to 200 feet if high-level disinfection is provided, Class I reliability is provided, and if soils hydrology, well construction, hydraulic loading rates, reclaimed-water quality, and expected travel time of groundwater to the potable water supply provides reasonable assurance that water quality standards will be met at the well (FAC 62-610.521).

5.4.2 Rapid-Rate Land Application Systems

Rapid-rate land application also involves the discharge of treated water to the land's surface and the eventual recharge of the underlying aquifer. However, rapid-rate systems have a much faster percolation rate than slow-rate systems. Rapid-rate systems are typically designed with hydraulic loading rates between 1.6 and 25 cm/day over the area of the basins (Kadlec and Knight, 1996). No wet-weather backup system is required for rapid-rate land application. Rapid-rate land application systems are also required to meet groundwater quality criteria at the edge of a zone of discharge.

Because of the potential for faster migration of discharged water, treatment standards for rapid-rate systems are higher. For rapid-rate land application, Florida regulations require secondary treatment with high-level disinfection (FAC 62-610). The following standards of water quality must be met:

- Total suspended solids must be less than 5 milligrams per liter (mg/L) before disinfection
- Total nitrogen (total N) must be less than 10 mg/L
- Treatment must meet drinking-water standards.

High-level disinfection with filtration is effective at inactivating viruses, bacteria, and pathogenic protozoans in reclaimed water, especially if monitoring for removal of protozoans is conducted (York et al., 2002).

5.4.3 Wetland Systems

Florida's domestic wastewater-to-wetlands rule controls the quantity and quality of treated wastewater discharged to wetlands while protecting the type, nature, and function of wetlands. This is codified in chapter 62-611 FAC. The wastewater-to-wetlands rule regulates the quality of water discharged from wetlands to contiguous surface waters. It also provides standards for water quality, vegetation, and wildlife to protect wetland functions and values and establishes permitting and monitoring requirements for discharges of treated wastewater to wetlands. This rule allows the use of constructed wetlands and altered wetlands for discharge of treated wastewater to create and restore wetlands (FDEP, 2001e).

Reclaimed wastewater that is discharged to wetlands must undergo secondary treatment with nitrification to further reduce the concentration of nitrogen. The treated reclaimed wastewater must meet the following standards:

- Carbonaceous biochemical oxygen demand must be less than 5 mg/L
- Total suspended solids must be less than 5 mg/L
- Total nitrogen (as N) must be less than 3 mg/L
- Total phosphorus (as P) must be less than 1 mg/L.

Discharge to wetlands can be beneficial in several ways. Wetlands provide additional filtration to discharged waters, thereby improving effluent quality. Inputs of water help to maintain the wetland ecosystem. In some locations (for example, the Wakodahatchee Wetlands facility in Palm Beach County), rapid-rate land application systems have been converted to wetland treatment systems. The Wakodahatchee Wetlands receive approximately 2 mgd of highly treated reclaimed water. This water serves to maintain various types of wetland habitats for wildlife (FDEP, 2001e).

Treatment wetlands are prohibited within the boundaries of Class I or Class II waters (designated as Outstanding Florida Waters), or areas of critical state concern, or when the wetland is exclusively herbaceous. Groundwater and drinking-water quality standards are not specifically referenced in the wetland applications regulations. However, secondary treatment with nitrification generally assures that drinking-water standards will be met. According to a recent review of data from Florida reclaimed-water facilities, treatment systems that provide nitrification may also be more effective in removing pathogenic protozoans (York et al., 2002). Monitoring for fecal coliforms as an indicator of wastewater pathogens is required in treatment wetlands.

Disinfection of secondary-treated wastewater with chlorine (used in both basic disinfection and high-level disinfection) is highly effective at inactivating nearly all bacteria and viruses. Although there are no numerical water quality standards regulating the concentrations of pathogenic protozoans in treated wastewater, the Florida DEP recommends that no more than 5.8 *Cryptosporidium* oocysts per 100 L and no more than 1.4 *Giardia* cysts per 100 L be allowed in reclaimed water. Filtration is the preferred method of removing pathogenic protozoans, although the DEP has found that filtration is not always effective (York et al., 2002).

5.5 Problem Formulation

In this section, the potential risks that may be associated with the aquifer recharge wastewater management option are described. In section 5.6, potential risks are analyzed.

In conducting the option-specific risk analysis for aquifer recharge, an effort was made to focus upon those reuse practices that best fit the broad definition of aquifer recharge and that are most widely used within the study area. Wetland systems, as well as rapid and slow-rate land application systems, are each used within the study area. However, for reasons outlined below, this option-specific risk analysis focused on rapid-rate land application systems (RIBs).

5.5.1 Slow-Rate Land Application Systems

Slow-rate land application systems often involve the use of reclaimed water to irrigate vegetated systems, which assist in wastewater polishing and disposal. Irrigation rates are generally low or intermittent, allowing aerobic soil conditions to become established, if not continually, at least intermittently. Aerobic conditions in turn allow the growth of upland vegetation, which removes nutrients, filters wastewater solids, and creates more permeable soils. Slow-rate land application of treated wastewater is used throughout the United States (Kadlec and Knight, 1996).

In South Florida, slow-rate land application nearly always means irrigation, including irrigation of public-access areas and landscape areas (for example, golf courses, parks, highway medians, and cemeteries), and agricultural irrigation. In addition to plant uptake and evapotranspiration (water loss to the atmosphere because of plant respiration), a portion of the applied water may percolate to groundwater.

Following treatment, reclaimed water may still contain nutrients such as nitrogen, phosphorus, and other substances that act as nutrients. If such reclaimed water is applied to vegetated areas, additional nutrient removal can be expected because of uptake by vegetation. Vegetation is often used as a “polishing” agent to help remove nutrients in wastewater treatment, and there are some wastewater treatment approaches that are based largely upon the use of plants to remove nearly all pollutants. Wetland treatment systems in particular rely heavily upon vegetation to remove or reduce pollutants.

The efficacy of removal of nutrients and other substances by plants depends upon many factors, such as the rate of application, concentration of nutrients in the treated water being applied to vegetation, plant species used, rate of nutrient uptake by plants, microbial processes that may further affect uptake rates, soil type, moisture, pH, temperature, whether other sources of nutrients also happen to be present, and length of exposure time (Kadlec and Knight, 1996).

If the rate of nutrient application equals the total rate of uptake by vegetation and all other uptake processes, then there should be little or no excess nutrients. Similarly, if irrigation with reclaimed water does not occur at a rate that exceeds the rate of uptake by vegetation and all other uptake processes, there will be little or no recharge of groundwater. Reuse systems that involve application to vegetated areas are typically operated so as to take into account a specific water budget and assimilative capacity. However, if the plants' capacity for water and nutrient uptake is less than the rate of application, excess water and nutrients will percolate without the beneficial functions of nutrient removal and water reuse that plants may provide.

Biodegradation of many wastewater constituents in soils and vegetation can also be expected. Biodegradation processes in soil include microbial uptake and transformation, microbially mediated decomposition of organic matter, microbial volatilization or solubilization, and further transformations as the breakdown products pass through the food chain to higher organisms (Brock et al., 1984; Kadlec and Knight, 1996). Microorganisms are important in the biogeochemical cycling of biologically important elements, including carbon, nitrogen, phosphorus, sulfur, iron, manganese, and silica, and play an important role in the decomposition of rocks and soils (Krumbein et al., 1983). Biological degradation of pesticides, petroleum products, metals, and other pollutants is often accomplished through microbial processes (Kadlec and Knight, 1996).

Facilities operating slow-rate land application systems are required to balance the application of reclaimed water with evapotranspiration rates. Therefore, these facilities do not typically operate their land application systems during periods of wet weather. Slow-rate land application systems are not likely to provide significant recharge to groundwater. Risks are expected to be very low to nonexistent.

5.5.2 Rapid-Rate Land Application Systems

Rapid-rate land application systems discharge treated wastewater to RIBs and absorption fields with highly permeable soils. RIBs involve a series of basins that may include subsurface drains, which are designed to receive and distribute reclaimed water. Absorption fields include subsurface absorption systems that may include leaching trenches, pipes, or other conduits to receive and disperse water underground. They are typically covered with soil and vegetation.

Rapid-rate application systems are typically loaded at hydraulic loading rates between 1.6 and 25 cm/day over the area of the basins (Kadlec and Knight, 1996). Absorption fields must be designed and operated to avoid saturated conditions at the ground surface. Projects proposed in areas with unfavorable hydrogeology (for example, karst) or other unfavorable characteristics must meet additional levels of treatment, as described below.

The use of rapid-rate land application may result in significant volumes of reclaimed water directly recharging the surficial aquifer. There is little potential for reduction in volume or additional removal of stressors by in situ natural attenuation processes, because of the large volumes applied and the rapid application rate. Because larger volumes of reclaimed water are applied and only an intermediate level of treatment is used, this form of aquifer recharge may pose the highest risks. Therefore, this option-specific risk analysis and risk assessment focuses on rapid-rate land application.

5.5.3 Wetland Systems

Wetlands, which are wet or inundated during part or all of the year, are often transitional areas between uplands and permanently flooded aquatic basins, such as lakes, ponds, lagoons, or coastal embayments. Wetlands are characterized by vegetation that has adapted to living under wet or occasionally inundated conditions and by hydric soils that develop chemical and physical characteristics related to low oxygen and frequent or constant exposure to water (US Army Corps of Engineers, 1987; Dennison and Berry, 1993; Cowardin et al., 1979). Wetlands are characterized by high rates of biological activity and productivity relative to upland ecosystems, making them capable of transforming and neutralizing many of the constituents found in treated wastewater (Kadlec and Knight, 1996).

Wetland systems or wetland treatment systems involve the application of reclaimed water to existing wetlands for the purpose of restoring wetlands and providing further treatment of water. Wetland reuse systems may provide more significant amounts of recharge to groundwater, particularly where there are direct hydrologic connections between the wetland and groundwater systems.

However, where perched wetlands exist because of the presence of a relatively impermeable soil layer (for example, clays, organic matter) that slows or prevents direct hydrologic connection with the underlying aquifer, a wetland may actually retard recharge of groundwater. The major difference between wetland systems receiving reclaimed water and all other types of aquifer recharge is that wetlands, particularly natural wetlands, will typically contain more ecological receptors than human receptors. Because discharge to wetlands is analogous to surface-water discharge of treated wastewater, the evaluation of risks from wetlands discharge is discussed in Chapter 7.

5.5.4 Florida DEP Study of Relative Risks of Reuse

In this risk assessment, information from a Florida DEP study of the risks of reclaimed water was integrated into the fate and transport analysis (FDEP, 1998). The Florida DEP risk study provided a qualitative ranking of the relative human health risks of reuse of reclaimed water that involves release to surface water or groundwater used for drinking-water supplies. The DEP study was intended to support state rulemaking. The qualitative ranking of various reuse options was based on the best professional judgment of professionals in regulatory agencies and other groups and on the $1x10^{-4}$ threshold for risk (that is, there is a 1-in-10,000 chance of a stressor causing illness or other adverse effect in consumers). However, according the DEP, the $1x10^{-4}$ risk threshold may not be appropriate for defining microbial risk thresholds.

The DEP's relative-risk ranking assigns a relative risk from 1 (high) to low (25) for various reuse activities using reclaimed wastewater. Injection of reclaimed water to aquifers, aquifer storage and retrieval using reclaimed water, discharge to Class I surface waters (drinking-water sources), and injection for salinity barriers were rated as the six highest-risk activities. Rapid-rate infiltration systems in karst (RIBs) ranked 7th, discharge to surface waters hydrologically connected to groundwaters ranked 11th, discharge to wetlands ranked 14th, rapid-rate infiltration systems in suitable geology ranked 15th, slow-rate systems ranked 17th, and irrigation of public-access areas ranked 18th. The lowest risk ranking was assigned to lined storage ponds.

Based on the DEP's relative-risk ranking of various reuse options for reclaimed wastewater, rapid-rate infiltration systems were selected as a higher-risk form of aquifer recharge (excluding injection, ASR using reclaimed water, and salinity barriers) for this risk assessment. Selection of a higher-risk form of aquifer recharge provides a conservative or protective approach to risk assessment.

5.5.5 Potential Stressors

Potential stressors entrained or dissolved in the reclaimed water are discharged to RIBs. Wastewater constituents that may act as stressors to human or ecological health include pathogenic microorganisms, certain metals and inorganic substances, synthetic and volatile organic compounds, and hormonally active agents.

Rapid-rate land application systems are required to meet groundwater quality criteria at the lower edge of a discharge zone. Accordingly, most systems that utilize RIBs are operated in such a way that concentrations of stressors are substantially reduced before reclaimed water reaches and recharges the underlying aquifers.

The primary source of potential stressors is the effluent from wastewater treatment plants (that is, reclaimed water) that is discharged through one or more aquifer recharge facilities and eventually percolates to reach the underground surficial aquifer, a formation containing underground sources of drinking water (USDWs). Stressors include reclaimed water constituents such as metals and other inorganic elements; compounds such as inorganic nutrients (nitrate, ammonium, and phosphate); volatile and synthetic organic compounds; microorganisms that survive basic or high-level disinfection or are resistant to disinfection, such as pathogenic protozoans; and miscellaneous constituents. Chlorination, and especially high-level disinfection, is effective at inactivating bacteria and viruses; however, cyst-forming pathogenic protozoans, such as *Cryptosporidium parvum*, *Giardia lamblia*, are only removed through filtration designed for their removal (York et al., 2002).

Potential risks associated with the use of emergency ponds to receive wastewater during upset bypass conditions, such as storms or other events resulting in large volumes of wastewater, can also be characterized using this conceptual model. Exposure pathways, receptors, and assessment endpoints are similar; concentrations and types of stressors may differ.

5.5.6 Potential Receptors and Assessment Endpoints

Potential drinking-water receptors include USDWs beneath the RIB, other USDWs to which groundwater flow may carry potential stressors, public and private water-supply wells, and surface waters. Federal drinking-water standards (maximum contaminant levels (MCLs)) and other health-based standards serve as the analysis endpoints for assessing risks to each of these potential drinking water receptors.

The USDWs that may be recharged by RIBs include the unnamed surficial aquifers and the Biscayne Aquifer. The surficial aquifers are used for domestic private water supplies and for municipal water supplies in central South Florida and along the east and west coasts (Randazzo and Jones, 1997). The Biscayne Aquifer is tapped by private wells and also supplies large public water systems in Dade, Broward, and Palm Beach counties. Water obtained through private wells is often used directly (without pretreatment). Community and municipal water systems generally do pretreat groundwater before distribution.

Utilities in South Florida make limited use of surface water bodies as sources of drinking water. Nevertheless, migration of wastewater constituents to these sources of drinking water is a possibility; surface water bodies are potential drinking-water receptors.

Potential ecological receptors include surface water bodies and the biological communities they support. The state of Florida surface-water quality standards for Class I waters and known ecological dose-response thresholds serve as the assessment endpoints for assessing risks to potential ecological receptors.

5.5.7 Potential Exposure Pathways

When drinking-water or ecological receptors are exposed to wastewater constituents in sufficient concentration, these receptors may be at risk for potentially adverse health effects. The complex set of processes and interactions that govern how reclaimed water will move and behave in the subsurface define the pathways that may expose receptors to such concentrations.

Dissolved and entrained wastewater constituents move through soils and geologic media under the influence of physical, chemical, and biological processes. These processes govern the movement of water and the fate and transport of stressors present in the water. Pathways of reclaimed-water migration, and the processes that may modify its constituents, are dependent upon both the hydrogeologic system into which the reclaimed water has been recharged and the nature of the constituents themselves.

Conservative (nonreactive) constituents will move through the hydrogeologic system unaffected by chemical or biological processes. Concentrations of conservative constituents are diluted in groundwater through advection (groundwater flow) or diffusion. On the other hand, concentrations of wastewater constituents that are subject to chemical and biological transformation will be influenced by abiotic processes (that is, ion exchange, adsorption), by biological degradation or transformation, and by dilution in the subsurface.

The highly permeable limestone formations of the Biscayne Aquifer and the less permeable formations of the surficial aquifers provide pathways for migration of reclaimed-water and wastewater constituents. Groundwater transport of these constituents may result in migration from the point of recharge to a receptor well or surface water body.

Following recharge, inorganic and organic wastewater constituents that are not removed by the treatment process will be entrained in the effluent. As the effluent moves through the subsurface soil and rocks during advection, these constituents will be subject to a number of physical, chemical, and biological processes such as dilution, absorption, chemical transformation, volatilization, and other processes.

5.5.8 Conceptual Model of Potential Risks of Aquifer Recharge

A generic conceptual model for the aquifer recharge wastewater-management option is presented in Figure 5-1. The primary source of potential stressors is defined as the wastewater treatment plant from which reclaimed water is distributed to one or more rapid-rate land application systems.

Reclaimed water is discharged to RIBs located directly above surficial aquifers. RIBs are generally located tens of feet (not hundreds or thousands of feet) above the water tables receiving the recharge. Underlying surficial aquifers are typically USDWs of potable-water quality (less than 1,500 mg/L total dissolved solids content).

For aquifer recharge, the expected principal exposure pathway is migration of reclaimed water from the point of recharge by rapid-rate land application systems to the USDW. Groundwater may also carry reclaimed-water constituents to areas where groundwater discharges to surface water, potentially affecting ecological receptors.

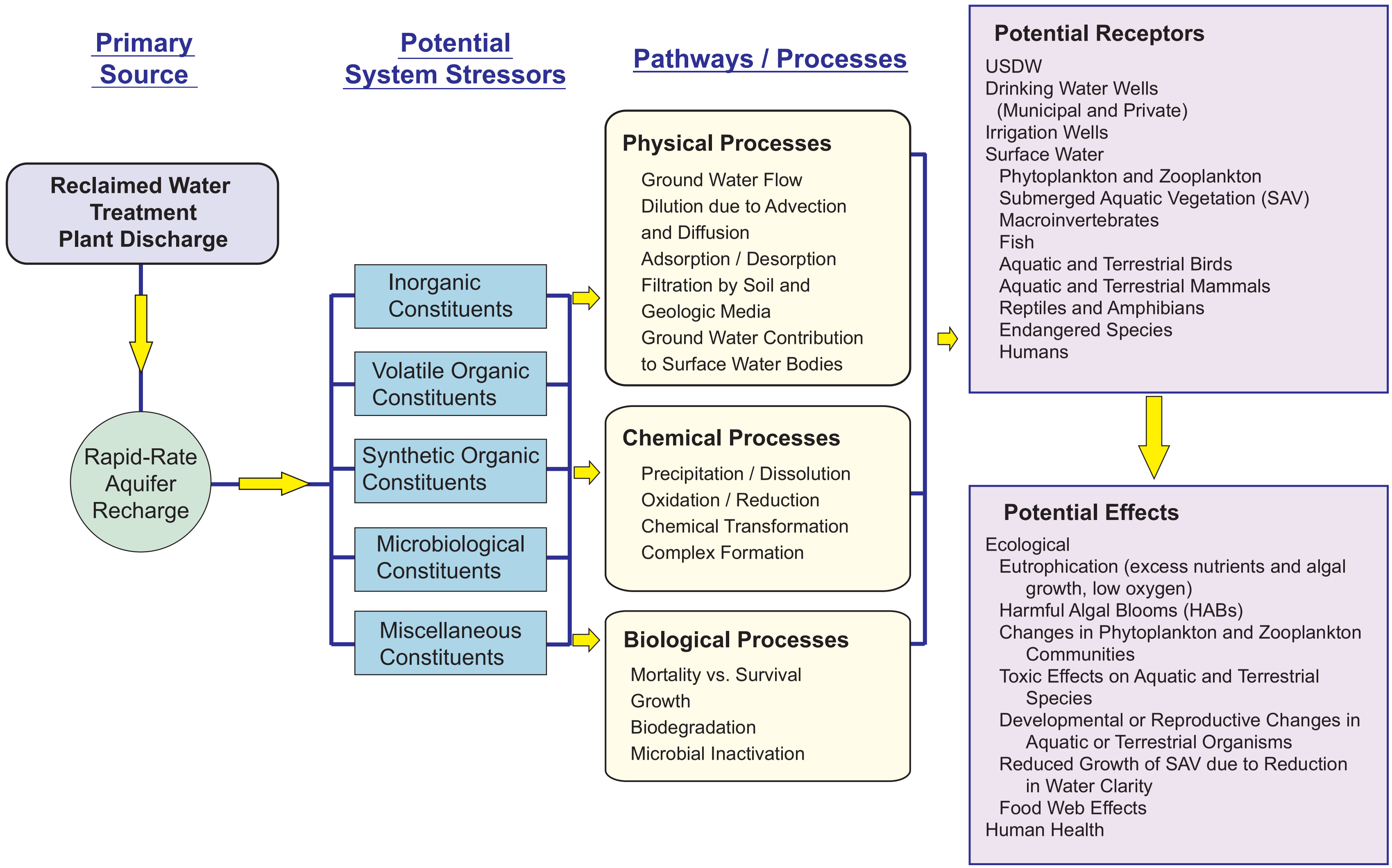

Figure 5-1. Conceptual Model of Potential Risks for the Aquifer Recharge Option

The dissolved and entrained constituents move through the geologic media under the influence of physical, chemical, and biological processes governing water movement and the fate and transport of the stressors in groundwater. The surficial aquifer may also act as a secondary source of dissolved and entrained stressors that may be carried to other parts of the aquifer where receptors may be exposed.

5.6 Risk Analysis of the Aquifer Recharge Option

In this section, information on stressors, receptors, and exposure pathways are used to examine potential risks and evaluate the conceptual model for aquifer recharge.

This analysis evaluates how reclaimed water may be transported horizontally within USDWs away from the point of recharge. Estimated times of travel are used to characterize the fate and transport of wastewater constituents (stressors) present in the reclaimed water. The fate and transport equations used in chapter 4 for evaluation of deep injection-well disposal are valid for aquifer recharge as well.

Information concerning potential stressors was obtained from effluent water quality monitoring reports required by the state of Florida and from a review of the scientific literature. To describe the proximity and vulnerability of receptors, publicly available information was obtained regarding the locations of public water-supply intakes. A review of the scientific literature provided information regarding the locations and physical extent of USDWs in South Florida. Information necessary to characterize possible exposure pathways was obtained from scientific literature describing the study area's soils, geology, and hydrology.

5.6.1 Vertical and Horizontal Times of Travel

Analyzing the transport of discharged effluent involves the analysis of the time of travel, which is the time needed for discharged effluent to move in groundwater over a specified distance to a drinking-water receptor. In aquifer recharge, typically the discharge location is directly above the surficial aquifer, and therefore the migration pathway will be downward and outward from the point of application. The potential for migration will be affected by site-specific factors, including the following:

- Required setback distances
- Locations of potential receptors (water-supply wells)
- Local direction of groundwater flow
- The distance to potential receptor wells
- Surficial aquifer characteristics that govern groundwater flow velocity.

Required setback distances vary depending on facility operations and range from 200, 500, and 2,640 feet. Engineering reports for new facilities must identify all potable water supplies within 0.5 mile of the facility.

Representative hydrogeologic parameters for Dade, Brevard, and Pinellas counties were used to estimate the potential groundwater flow velocity and associated time for groundwater to travel 200 feet, 500 feet, and 0.5 mile (2,640 feet) in the surficial aquifer (Adams, 1992; Barr, 1996; Lukasiewiez and Adams, 1996; Reese and Cunningham, 2000). Assumptions, calculations, and results are provided in appendix 8 and are summarized in table 5–3. Since local hydrogeologic conditions in the surficial aquifer may vary significantly, these travel times are intended only to provide representative values.

Table 5-3. Effluent Travel Times in the Surficial Aquifer

Surficial Aquifer Location	Horizontal Distance (ft)	Travel Time	
		Days	Years
Dade County: horizontal hydraulic conductivity: 1,524 ft/day	200	41	0.11
	500	102	0.28
	2,640	537	1.47
Brevard County: horizontal hydraulic conductivity: 56 ft/day	200	1,107	3.03
	500	2,768	7.58
	2,640	14,614	40.01
Pinellas County: horizontal hydraulic conductivity: 29 ft/day	200	2,138	5.85
	500	5,345	14.63
	2,640	28,221	77.26

Note: hydraulic gradient = 0.001; porosity = 0.32.

The results of these calculations (table 5–3) indicate that the shortest estimated travel times for effluent to travel 200, 500, and 2,640 feet are predicted for Dade County, where the Biscayne Aquifer has a high hydraulic conductivity. Horizontal travel time is significantly longer, by approximately 2 orders of magnitude, in Brevard County. Pinellas County has the longest horizontal travel times. These estimates are based on constant porosity and constant hydraulic gradient, but varying hydraulic conductivity from region to region. Again, site-specific conditions may differ substantially from the values used.

These results indicate that, solely in terms of transport of effluent, the highest risks for aquifer recharge may be found in Dade County, where the time of travel is the lowest, and the lowest risks for aquifer recharge may occur in Pinellas County, where the time of travel is the highest.

5.6.2 Evaluation of Stressors

Monitoring data indicates that concentrations of wastewater constituents in reclaimed water used in aquifer recharge generally meet drinking-water standards for reclaimed water. Also, treated effluent generally meets or is better than standards for reclaimed water or advanced wastewater treatment effluent (see Appendix Table 1-1).

Several representative chemical elements and compounds, potentially found in reclaimed water recharged via rapid-rate systems, were chosen for fate and transport analysis. The analysis is designed to estimate the final concentration of these wastewater constituents by taking into account calculated travel times in groundwater, biodegradation, hydrolysis, and sorption processes. These natural attenuation processes will reduce the overall concentration of chemicals during transport in groundwater.

Examples of natural attenuation processes include sorption, biological degradation, and chemical transformation. Compounds and elements dissolved in groundwater are removed from solution by sorption onto geologic material. Such sorption-desorption reactions result in a slowing of movement of the compound or element in groundwater. Sorption may be reversible, however. Biological activity by microorganisms may also result in the degradation of organic material and may also mediate transformations of inorganic materials, resulting in decreasing concentrations over time. Hydrolysis is another process whereby organic and inorganic solutes react with water, resulting in degradation and transformation. Rates of biological degradation and hydrolysis reactions may be expressed as a half-life for specific compounds (that is, the time it takes the concentration of the compound or element to decrease to one-half of its original concentration).

Selected representative stressors included arsenic (As), chloroform ($CHCl_3$) (representing trihalomethanes), nitrate (NO_3), and di (2-ethyl) phthalate (DEPH). Chloroform and several other similar compounds known as trihalomethanes may be present in reclaimed water as a result of the chlorination process. The fate and transport characteristics of chloroform were selected to represent the potential for migration of all trihalomethanes. DEPH, a synthetic organic compound used as a plasticizer for polyvinylchloride (PVC) and in consumer products, is a suspected endocrine disruptor (ASTDR, 1993).

Concentrations of representative compounds were based on typical values for reclaimed water (presented in Table 5-4); these were obtained from a large data set of monitoring results for treated effluent (see Appendix Table 1-1). The concentration of chloroform was used as a representative of total trihalomethanes, a group of compounds that includes chloroform. Chloroform was selected for the analysis based on the availability of fate and transport information. All initial stressor concentrations in the data sets available met drinking-water standards. The selected concentration for DEPH was the detection limit reported for wastewater analyses.

Table 5-4. Initial Concentration of Representative Stressors in Reclaimed Water

Compound	Initial Concentration
Arsenic	0.003 mg/L
Chloroform	26.85[1] (µg/L)
Di (2-ethylhexyl) Phthalate (DEPH)	5.0[2] (µg/L)
Nitrate	3.69 (mg/L)

[1]Concentration of total trihalomethanes.
[2]DEPH detection limit.

In addition to chemical stressors, the pathogenic protozoans *Cryptosporidium parvum* and *Giardia lamblia* were selected for evaluation of biological stressors that may be present in reclaimed water (York et al., 2002).

Florida's reuse rules have required monitoring for pathogenic protozoans since 1999. Results of monitoring through September 2001 were reviewed by York et al. (2002). Based on 48 observations, *Cryptosporidium* was detected in 23% of observations, with 8.3 % (3 observations) having more than 5 oocysts per 100 L. *Giardia* was detected in 58% of observations, with 46% of observations having more than 5 cysts per 100 L. Although there are no specific reclaimed water standards for pathogenic protozoans, the Florida DEP encourages improvements in the filtration process at facilities where greater than 5.8 *Cryptosporidium* oocysts or cysts per 100 L are detected or greater than 1.4 *Giardia* cysts are found per 100 L (York et al., 2002).

5.6.3 Evaluation of Receptors and Assessment Endpoints

Based on required treatment levels and review of data from wastewater treatment facilities utilizing aquifer recharge for wastewater management, representative concentrations of chemical stressors were selected. These stressor concentrations were used in fate and transport analyses based on travel distances of 200 feet, 500 feet, and 0.5 mile (2,640 feet), which were selected based on required setback distances and reporting requirements. The procedures described in section 4.3 for fate and transport of stressors in effluent injected to deep wells were applied to aquifer recharge. Referenced soil sorption coefficients and half-lives for representative stressors used in chapter 4 were used in this analysis to calculate attenuation of stressors during transport. Results of the fate and transport analysis are presented in Table 5-5.

Table 5-5. Contaminant Transport and Fate in the Surficial Aquifer

	Chloroform (µg/L)	Arsenic (mg/L)	Di(2-ethylhexyl) Phthalate (DEPH) (µg/L)	Nitrate (mg/L)
Dade County (effluent travels 200 feet in 0.11 years; 500 feet, 0.28 years; 2,640 feet in 1.47 years)				
Contaminant travel time	For 200 ft., 0 yrs. For 500 ft., 0 yrs. For 2,640 ft., 2 yrs.	For 200 ft., 0 yrs. For 500 ft., 0 yrs. For 2,640 ft., 2 yrs.	For 200 ft., 0 yrs. For 500 ft., 0 yrs. For 2,640 ft., 2 yrs.	N/A
Concentration at injection	7.18	0.01	5.00	N/A
Concentration at 200 feet	7.06	0.01	4.56	0.64
Concentration at 500 feet	6.88	0.01	3.97	0.64
Concentration at 2,640 feet	5.73	0.01	1.48	0.64
MCL	80 (as trihalomethane)	0.05	6	10
Brevard County (effluent travels 200 feet in 3.03 years; 500 feet, 7.58 years; 2,640 feet in 40.01 years)				
Contaminant travel time	For 200 ft., 3 yrs. For 500 ft., 8 yrs. For 2,640 ft., 43 yrs.	For 200 ft., 3 yrs. For 500 ft., 9 yrs. For 2,640 ft., 45 yrs.	For 200 ft., 4yrs. For 500 ft., 9 yrs. For 2,640 ft., 48 yrs.	N/A
Concentration at injection	230	0.005	5.00	9.60
Concentration at 200 feet	146	0.005	0.5	9.60
Concentration at 500 feet	73.7	0.005	0.0	9.60
Concentration at 2,640 feet	0.6	0.005	0.0	9.60
MCL	80 (as trihalomethane)	0.05	6	10
Pinellas County (effluent travels 200 feet in 5.85 years; 500 feet, 14.63 years; 2,640 feet in 77.26 years)				
Contaminant travel time	For 200 ft., 6.5 yrs. For 500 ft., 16.3 yrs. For 2,640 ft., 86.1 yrs.	For 200 ft., 7.12 yrs. For 500 ft., 17.80 yrs. For 2,640 ft., 93.97 yrs.	For 200 ft., 9.9yrs. For 500 ft., 19.8 yrs. For 2,640 ft., 104.6 yrs.	N/A
Concentration at injection	6.7	0.003	1.25	0.28
Concentration at 200 feet	2.68	0.003	0.01	0.28
Concentration at 500 feet	0.68	0.003	0.00	0.28
Concentration at 2,640 feet	0.00	0.003	0.00	0.28
MCL	80 (as trihalomethane)	0.05	6	10

Dilution and dispersion of stressors in groundwater were not considered in this analysis. These groundwater processes could result in lower concentrations at the 1,000-foot distance. Local hydrologic conditions may result in longer or shorter travel times.

The shortest estimated travel times for effluent to reach receptor wells in the surficial aquifer were in Dade County, where effluent travel times to reach wells at 200 feet, 500 feet, and 2,640 feet were 0.11, 0.28, and 1.47 years, respectively. Such short travel times pose relatively higher risks than longer travel times found elsewhere in South Florida. However, because concentrations of representative chemical stressors in discharged effluent were below their respective drinking-water MCLs, the final concentrations of representative stressors at the receptor wells were also below MCLs. Therefore the human health risks do not appear to be significant for these stressors and these travel times.

In Dade County, some stressors (for example, chloroform, DEPH) underwent further reduction as they traveled in the migrating effluent and decreased in concentration during their migration. However, the reduction amounts to less than a full order of magnitude reduction. Some other stressors (for example, arsenic, nitrate) did not undergo any decrease in concentration as they traveled through the shallow aquifer.

In Brevard County, estimated travel times for effluent in groundwater were intermediate in value. Effluent travel times to reach 200, 500, or 2,640 feet were 3.03 years, 7.58 years, and 40.01 years, respectively. For chloroform, effluent quality was elevated at injection (230 μg/L), but reduced to below the MCL at 500 feet. Like Dade County, final concentrations of all stressors, whether nonconservative or conservative, were below their MCLs. The modeled final concentration of one stressor, DEPH, fell to 0.00 at a distance of 500 feet, after an estimated travel time of 9 years. Again, like Dade County, the human health risks do not appear to be significant for these stressors and travel times.

The longest estimated travel times for effluent were found in Pinellas County. Estimated effluent travel times to reach 200, 500, and 2,640 feet were 5.85, 14.63, and 77.26 years, respectively. Initial concentrations of all stressors evaluated were below MCLs. The modeled final concentration of chloroform fell to 0.00 at a distance of 2,640 feet and a travel time of 86 years. The modeled final concentration of DEPH fell to 0.00 at a distance of 500 feet and a travel time of 19.8 years. Long travel times represent the lowest risk. Again, like Dade and Brevard counties, there do not appear to be any human health risks for the compounds and substances regulated.

Because reclaimed water treatment involves both basic disinfection and high-level disinfection using chlorine, which effectively inactivates most viruses and bacteria, reclaimed wastewater does not appear to pose any significant human health risk in terms of pathogenic bacteria or viruses (York et al., 2002).

However, pathogenic protozoans that are not inactivated by chlorine may pose concerns, particularly if reclaimed water is not filtered adequately. Pathogenic protozoans such as *Cryptosporidium parvum* and *Giardia lamblia* oocysts may be capable of surviving for relatively long periods of time in groundwater and surface water, based on laboratory studies (There are very few in situ studies of oocyst inactivation). The most complete review of survival of *Cryptosporidum* is that by Walker et al. (1998). This review describes studies by Mawdsley et al. (1996a), who concluded that runoff contaminated with oocysts posed a more significant threat to water quality than infiltration through the soil profile, because of straining that tends to slow the transport of microorganisms (McDonald and Kay, 1981). For these reasons, the Florida DEP recommends that reclaimed wastewater should not contain more than 5.8 *Cryptosporidium* oocysts per 100 L or more than 1.4 *Giardia* cysts per 100 L (York et al., 2002). However, this is not yet a regulatory requirement.

Cryptosporidium and *Giardia* also occur in groundwater and surface water in South Florida (Rose et al., 2001; York et. al., 2002). The potential for aquifer recharge practices to remobilize *Cryptosporidium* or *Giardia* cysts derived from other sources cannot be evaluated in this study because of the lack of information concerning site-specific monitoring for pathogenic protozoans.

In summary, pathogenic protozoans that are not removed by chlorination pose the highest health risks associated with this wastewater management option. However, it should be pointed out that pathogenic protozoans are widespread in many natural surface water bodies and in groundwater, from a variety of sources (agricultural runoff, domestic animals, and, in particular, calves) (York et al., 2002; Walker et al., 1998). These concentrations in natural surface waters frequently exceed the amounts typically found in reclaimed water (see Table 5-6).

Other chemical constituents of treated reclaimed wastewater appear to generally meet or are lower than drinking-water standards.

Concentrations of nitrate and other nutrients that may remain in reclaimed water even after removal of nitrogen may pose ecological concerns, because most natural aquatic systems do not contain nitrate concentrations above the range from a few tenths of a ppm to several ppm

Table 5-6. Comparison of *Cryptosporidium* Concentrations in the Environment

Water Type (and Location)	Average (oocysts/100 L)	Range (oocysts/100 L)	Notes
Reclaimed water (St. Petersburg)[1]	0.75	ND – 5.35	12 samples
Phillippi Creek (FL)[2]	16	ND – 158	16 samples from urban stream in Sarasota
Five streams (FL)[2]	6.6	ND – 157	24 samples near Sarasota
Sarasota Bay (FL)[2]	ND	ND	4 samples from high-quality estuary
Tampa Bypass Canal (FL)[3]	3.1	ND – 11	7 samples
Filtered drinking water[4]	1.52	ND – 48	66 water-treatment plants in 14 states and 1 Canadian province (85 samples)
Treated drinking water[5]	3.3	ND – 57	1991–1993, 262 samples at 72 water plants
Surface-water supplies for drinking-water plants[5]	240	ND – 6,510	1991–1993, 262 samples at 72 water plants
Groundwaters[6]	41	—	74 samples
Springs[7]	4	—	7 samples
Lakes (pristine)[7]	9.3	ND – 307	34 samples
Rivers (pristine)[7]	29	ND – 24,000	59 samples
Surface waters (all categories)[7]	43	ND – 29,000	181 samples in 17 states
Irrigation canals (AZ)[8]	555,000	530,000–580,000	2 samples
Rivers in protected watershed[9]	2	ND – 13	6 samples, western United States

[1]Rose and Carnahan, 1992.
[2]Rose and Lipp, 1997.
[3]Rose, 1993.
[4]LeChevallier et al., 1991.
[5]LeChevallier and Norton, 1995.
[6]Rose, 1997.
[7]Rose et al., 1991.
[8]Madore et al., 1987.
[9]Rose, 1988.
ND = nondetectible
Source: Florida DEP, 1998.

5.7 Final Conceptual Model of Probable Risk

A final conceptual model of probable risk was developed as described below.

Aquifer recharge is broadly defined in this risk assessment as the replenishment or recharge of a groundwater aquifer through a variety of application methods, including rapid-rate land application, slow-rate land application, irrigation, and discharge to wetlands that are hydrologically connected to groundwater. The aquifers of concern in South Florida are the Biscayne and surficial aquifers, which are highly permeable and are susceptible to contamination from a large variety of point and nonpoint sources. In South Florida, the leading use of reclaimed wastewater is for irrigation of public-access areas (158.24 mgd), followed by industrial uses (59.1 mgd), groundwater recharge (31.72 mgd), irrigation of restricted access areas (27.5 mgd), and discharge to wetland systems (10.44 mgd).

Aquifer recharge using wastewater treated to reclaimed-water standards is called reuse in the state of Florida and is regulated under Florida's reuse regulations. Beneficial uses of reclaimed water includes aquifer recharge to restore or maintain aquifers, creation or restoration of wetlands that have been adversely affected by human activities, and creation of barriers to saltwater intrusion in coastal areas where withdrawal of fresh groundwater has exceeded natural recharge rates. Beneficial uses also include the use of reclaimed water for irrigation, which helps to conserve high-quality drinking-water resources.

Although ASR can be conducted with reclaimed water, most ASR being discussed in Florida involves the injection of high-quality water into aquifers for storage and later retrieval. Therefore, ASR is not considered in this risk assessment.

Reuse regulations require that reclaimed wastewater be treated with secondary treatment with basic disinfection if reclaimed water is intended for use in restricted-access locations. In public-access areas, slow-rate application systems must use wastewater treated to secondary levels with high-level disinfection, at a minimum. Nitrification, which helps to remove nitrogen from the wastewater, generally ensures that drinking-water standards for nitrogen are met. Disinfection with chlorine, particularly high-level disinfection, is highly effective at inactivating viruses and bacteria. Monitoring for fecal coliforms as an indicator of wastewater pathogens is required in treatment wetlands.

Filtration, which is required to reduce concentrations of total suspended solids, also reduces concentrations of pathogenic oocyst-forming protozoans, such as *Cryptosporidium parvum* and *Giardia lamblia*. Although there are no numerical water-quality standards regulating the concentrations of pathogenic protozoans in treated wastewater, the Florida DEP recommends that no more than 5.8 *Cryptosporidium* oocysts per 100 L and no more than 1.4 *Giardia* cysts per 100 L be allowed in reclaimed water. Filtration is the preferred method of removing pathogenic protozoans, although the DEP has found that filtration is not always effective (York et al., 2002).

Reuse regulations also require setbacks for aquifer recharge from public water-supply wells, surface-water supplies, and public-access areas. These setback distances vary, depending on the particular reuse option, from 75 feet to 500 feet or more. Such setbacks help to protect public water supplies from potential contaminants in surface-water runoff and in groundwater.

Figure 5-1 presents the generic conceptual model for the aquifer recharge wastewater management option. The primary source of potential stressors was defined as rapid-rate land application systems using reclaimed wastewater. In this conceptual model, reclaimed water is discharged to RIBs located directly above surficial aquifers. RIBs are generally located tens of feet (not hundreds or thousands of feet) above the water table. The principal exposure pathway in aquifer recharge was postulated to be migration of reclaimed water from the discharge point to the USDW. Groundwater may also carry reclaimed water constituents to areas where groundwater discharges to surface water, potentially affecting ecological receptors.

This option-specific risk assessment used an analysis of fate and transport of discharged reclaimed wastewater and representative chemical and microbiological constituents of wastewater, applied to rapid-rate land application. The fate-and-transport analysis was based on an analysis of the movement of discharged effluent in groundwater, estimation of the time of travel needed for effluent water to reach a drinking-water receptor such as a water supply well, and estimation of the fate of chemical constituents within the time of travel, using half-lives of chemical compounds and other characteristics. The approach used is the same as that used in chapter 4 for the fate-and-transport analysis of effluent discharged from Class I deep injection wells, except that the discharged effluent in aquifer recharge is moving down towards the aquifer rather than migrating upward towards the aquifer. Porous media flow is assumed for aquifer recharge.

The analysis of estimated travel times for rapid-rate land application indicated that Dade County may have the shortest travel times for effluent and hence the highest risk of contaminating the aquifer. These travel times ranged from 0.11 years to 0.28 years and 1.47 years for effluent to travel 200 feet, 500 feet, and 0.5 miles, respectively. However, the fact that reclaimed water is treated to relatively high standards, and because attenuation further reduces the concentrations of constituents along the path of travel, means that the actual risk to human health is most likely nonexistent to very low. The only possible exception is where filtration is not done or is ineffective at removing pathogenic protozoans, as described below).

In Brevard County, effluent travel times ranged from 3.03 years to 7.58 years to over 40 years for effluent to travel 200 feet, 500 feet, and 0.5 miles, respectively. As in Dade County, concentrations of chemical constituents in reclaimed water meet drinking-water standards before discharge. Concentrations of nonconservative constituents decrease further over this time period, while concentrations of conservative constituents remain the same over time. For these reasons, aquifer recharge using reclaimed water is not expected to pose significant human health risks in Brevard County, with the possible exception of pathogenic protozoans, as described below.

Pinellas County has the longest estimated effluent travel times and hence the lowest relative risk of the three areas evaluated. Estimated effluent travel were 5.85 years, 14.63 years, and 77.26 years to travel 200 feet, 500 feet, and 0.5 mile, respectively. Initial concentrations of all wastewater constituents were below their MCLs, and the final concentrations of conservative constituents remained the same. Concentrations of nonconservative constituents decreased even further over these time periods. Again, there do not appear to be any human health risks posed by the chemical constituents of reclaimed water.

Of all possible wastewater constituents remaining after treatment, oocyst-forming pathogenic protozans, such as *Giardia lamblia* and *Cryptosporidium parvum,* probably pose the greatest risks to human health, particularly if filtration is not effective at removing these oocyst-forming protozoans below DEP-recommended levels of 1.4 and 5.8 oocysts per 100 L, respectively. However, even if filtration is not this effective, the risks would be roughly comparable to ingesting untreated water from other natural surface-water sources that are considered pristine or relatively unimpacted by human activities or animal wastes.

Since reclaimed water may contain higher concentrations of nutrients than those found in ambient surface waters, there could potentially be ecological effects in nearby surface water bodies that receive reclaimed water. Chapter 7 provides a full discussion of water-quality criteria for unimpacted natural surface water bodies.

5.8 Potential Effects of Data Gaps

Because of the variable nature of geology and soils across the study area and the relative lack of site-specific information regarding groundwater flow and times of travel, actual conditions may differ from those expected. These differences may affect the risk assessment of the aquifer recharge methods in important ways. Data gaps occur in the groundwater information used for modeling fate and transport and in data on the water quality of discharged effluent and groundwater monitoring. Some of the potential effects of such data gaps are the following:

- Local variations in geologic and hydrologic conditions may result in differences in travel time from recharge locations to receptor wells and surface water bodies.
- Because of the lack of monitoring wells in the Biscayne Aquifer, there is no ability to predict or foresee potential adverse effects on public water supplies, whether risks arise from this wastewater management options or other activities.
- If hydrologic connections between groundwater and surface water bodies exist, then that provides another exposure or transport pathway whereby surface waters may be affected by aquifer recharge. The information reviewed in this study did not permit such detailed conclusions to be made, and this is an aspect of aquifer recharge that should be investigated on a site-specific basis. Site-specific monitoring of movement and water quality of groundwater and surface water should be used to determine whether there is a direct hydrologic connection

between the groundwater that receives discharged reclaimed water and surface water bodies or wetlands.

- The fate and transport of preexisting contaminants in groundwater and soils beneath the recharge site are unknown. There is a possibility that such preexisting contaminants may become remobilized by application of reclaimed water from above, but there is no specific monitoring information to indicate whether this might actually occur.

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